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Combined top-down and bottom-up climate change impact assessment for the hydrological system in the Vu Gia- Thu Bon River Basin

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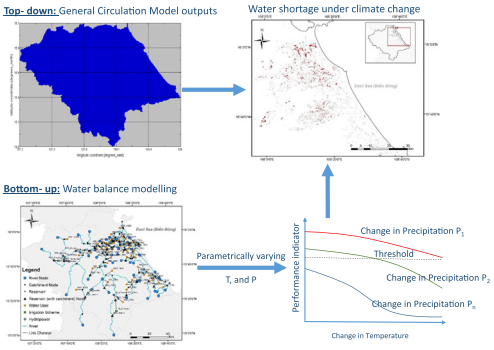
HIGHLIGHTS

- Combined top-down and bottom-up assessment in the Vu Gia- Thu Bon River Basin
- Water shortage expected to worsen due to climate change
- 8777 ha of crop was determined to be at risk due to water shortage in the future.
- Shortage of water between 11.8 million m^3 and 20.9 million m^3 expected

GRAPHICAL ABSTRACT



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ABSTRACT

Vu Gia- Thu Bon (VGTB) River Basin, located in the Central Coastal zone of Viet Nam currently faces water shortage. Climate change is expected to exacerbate the challenge. Therefore, there is a need to study the impacts of climate change on water shortage in the river basin. The study adopts a combined top-down and bottom-up climate change impact assessment to address the impacts of climate change on water shortage in the VGTB River Basin. A MIKE BASIN water balance model for the river basin was established to simulate the response of the hydrological system. Simulations were performed through parametrically varying temperature and precipitation to determine the vulnerability space of water shortage. General Circulation Models (GCMs) were then utilized to provide climate projections for the river basin. The output from GCMs was then mapped onto the vulnerability space determined earlier. In total, 9 out of 55 water demand nodes in the simulation are expected to face problematic conditions as future climate changes.

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1. Introduction

Vu Gia- Thu Bon (VGTB) River Basin, located in the Central Coastal zone of Viet Nam, currently faces water shortages. Rainfall in the river basin is temporally variable with a prolonged dry season. The dry season in the river basin spans 8 months within the year and contributes approximately 30% towards total annual precipitation. Prolonged dry conditions with limited rainfall create a huge challenge for water supply in the river basin. As water resources will be the principal medium climate change impacts are felt (García et al., 2014), the challenges of water management in the VGTB River Basin is likely to be exacerbated in the future.

There have been extensive studies into ways climate change impacts the water systems in general and in the VGTB in particular. Traditionally a top-down scheme is applied. While this approach produce optimal

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results for the intended future, its usability remains relatively limited in terms of decision support and policy design due to the uncertainties of climate change (Brown et al., 2012; Hallegatte et al., 2012). Uncertainties in climate projection often come in the form of various climate change scenarios. Variability from different projections can be large and to plan for one projection could strictly be contradictory to the other (Brown, 2011). Furthermore, the process of downscaling outputs from GCMs, and predicting socio-economic changes in the future entails large uncertainties. This creates a gap in translating climate information into adaptation policy (Dilling and Lemos, 2011).

For this reason, this study seeks to adopt a different approach with less reliance on the use of GCMs and to omit the use of GCMs downscaling in climate change adaptation for the VGTB River Basin. This is achieved through adopting the decision scaling framework. The result of the study includes better-tailored and more relevant climate change information that are useful for adaptation measures.

2. Study area

The VGTB River Basin is located in the Central Coastal Zone of Vietnam. The total catchment area of the river basin is approximately 10,350 km^2 and is shared between Da Nang City and Quang Nam Province in Vietnam (Fig. 1). Total population in the river basin is approximately 2 million inhabitants including those living in Da Nang City

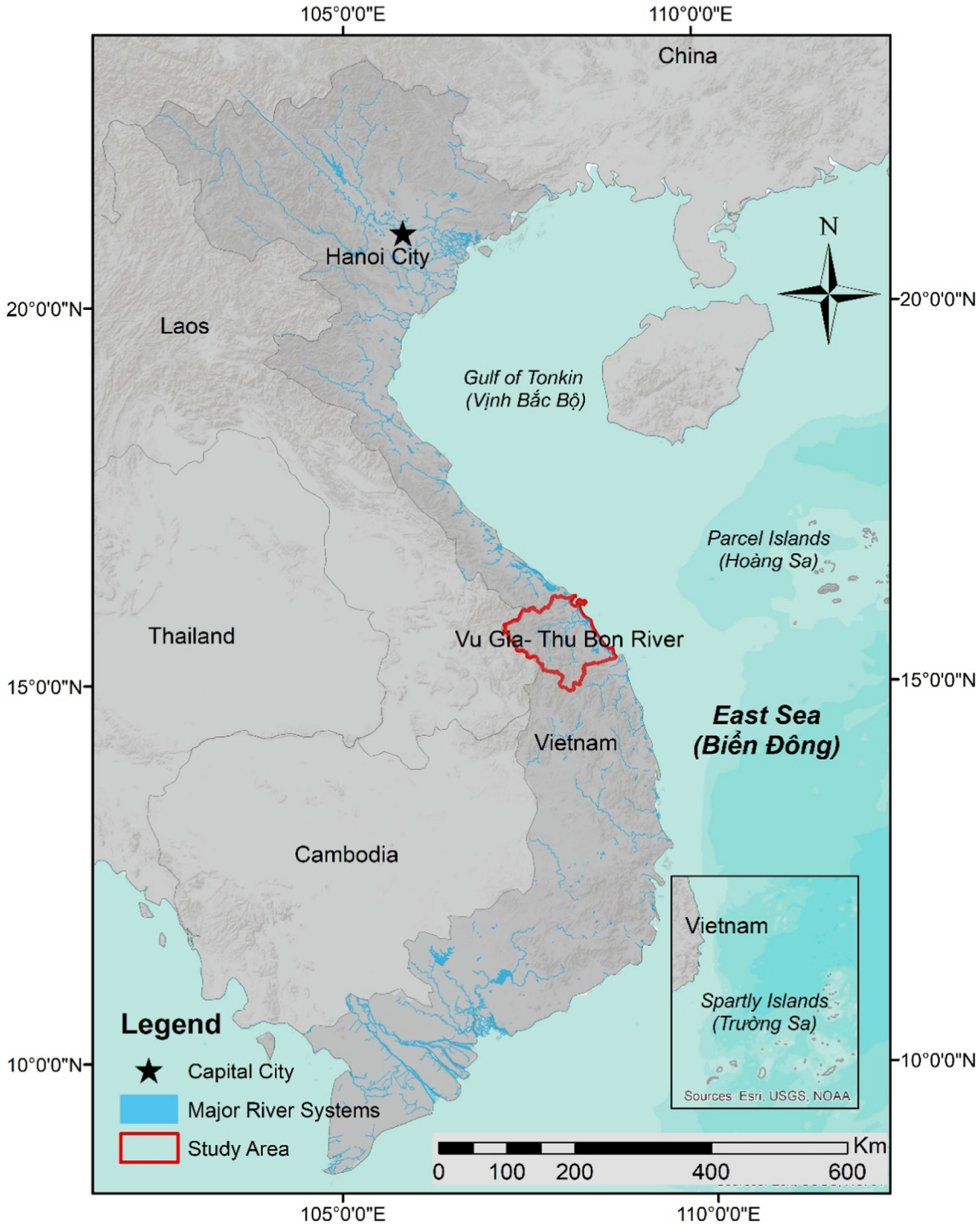

Fig. 1. Location of the study area.

Table 1
List of stakeholders and experts interviewed in the study.

No.	Organization/person	Role	Relevance in study area
1	Central Regional Center for Hydrology and Meteorology	Stakeholder	Hydrological- meteorology forecasting, drought warning for Quang Nam and Da Nang
2	Quang Nam Center for Hydrology and Meteorology	Stakeholder	Hydrological- meteorology forecasting, data collection, and drought warning for Quang Nam
3	Irrigation Company of Quang Nam	Stakeholder	Irrigation water supply for Quang Nam Province
4	Quang Nam Department of Agriculture and Rural Development	Stakeholder	Management of agriculture, irrigation, and disaster in Quang Nam
5	Da Nang Department of Agriculture and Rural Development	Stakeholder	Management of agriculture, irrigation, and disaster in Da Nang
6	Quang Nam Department of Natural Resources and Environment	Stakeholder	Management of natural resources (i.e. water, land use) in Quang Nam
7	Da Nang Department of Natural Resources and Environment	Stakeholder	Management of natural resources (i.e. water, land use) in Da Nang
8	Department of Water Resources Management	Stakeholder	National water resources management policies
9	Viet Nam Disaster Management Authority	Stakeholder	Management of disasters in Viet Nam (i.e. water shortages, droughts, etc.)
10	Viet Nam Institute of Meteorology, Hydrology and Climate Change	Expert	Leading research institute in Viet Nam on issues of meteorology, hydrology and climate change
11	Prof. Dr. Nguyen The Hung	Stakeholder, Expert	Local resident of Da Nang, experienced in climate change research in the area
12	Dr. Trinh Quoc Viet	Stakeholder, Expert	Local resident of Quang Nam, experienced in climate change research in VGTB
13	Mr. Duong Anh Diep	Stakeholder, Expert	Local resident of Da Nang, technical expert in the area
14	Mrs. Tran Thi Ha Van	Stakeholder, Expert	Local resident of Da Nang, familiar with research topic and area

and Quang Nam Province (2017 census). Agricultural production remains the most important economic sector in the river basin. The sector employs roughly half of the population in the basin (Viet, 2014). In addition, paddy rice remains the dominant crop with approximately 70% of irrigated agricultural area being rice.

3. Previous climate change impact assessment in the river basin

Early impact and adaptation studies of climate change in the VGTB River Basin adopted a scenario-based approach under given GCM scenario of the future climate. Within each scenarios, risks and vulnerability in future climate states are identified and adaptation responses proposed. The approach was presented as an analytical framework by the first United Nations Framework Convention on Climate Change Conference of the Parties in 1995 (Carter and Mäkinen, 2011). The approach is also commonly referred to as the top-down approach.

Previous notable top-down researches in the VGTB River Basin includes IMHEN (2010), DONRE (2012), Institute of Geography (2011), Nam et al. (2011), Lan and Son (2013), IMHEN and UNDP (2015), and Vo et al. (2016). IMHEN (2010) studied the impacts of climate change on the VGTB River Basin through downscaling the low (B1), the medium (B2), and the high emissions scenario (A2) from IPCC (2007) with a baseline period of 1980–1999. DONRE (2012) used downscaled scenarios in IMHEN (2010) and calculated drought indices for future climate conditions to study drought as a result of climate change. Similary, Institute of Geography (2011) and Lan and Son (2013) determined streamflow conditions based on the same downscaled scenarios from IMHEN (2010) to determine water shortages and flooding in the future. Nam et al. (2011) statistically downscaled the A1B scenario simulated by the CGCM model (MRI & JMA with a 300 km resolution) to provide an input for the super-tank runoff model. Vo et al. (2016) dynamically downscaled the CCSM3.0, MIROC-medres, and ECHAM5 GCMs under scenario A2 to drive the MIKE SHE model to determine river flow under climate change conditions.

A problem with the aforementioned top-down approach is their heavy reliance on GCM projections. GCMs are relatively poor scenario generators (Brown et al., 2012). Additionally, the process of GCM

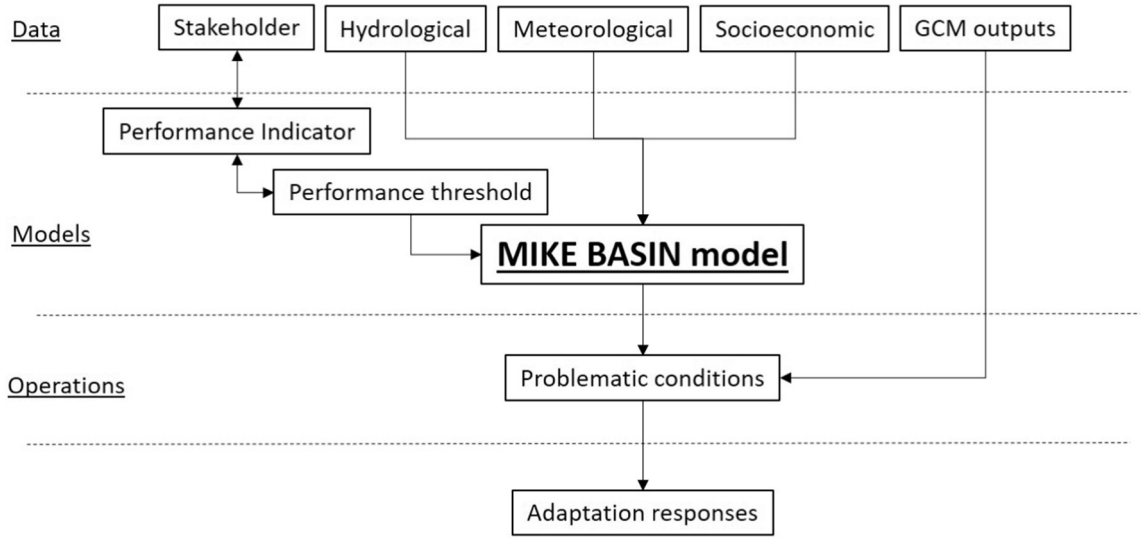

Fig. 2. Overall workflow of the research.

Table 2
Irrigation demand nodes.

Node in MIKE BASIN	Irrigation area (ha)	Node in MIKE BASIN	Irrigation area (ha)
IRR_VG01	65	IRR_TB20	823
IRR_VG02	71	IRR_TB21	515
IRR_VG03	586	IRR_TB22	140
IRR_VG04	120	IRR_TB16	685
IRR_VG05	425	IRR_TB23	233
IRR_VG06	200	IRR_TB24	080
IRR_VG07	387	IRR_TB03	52.8
IRR_VG08	2010	IRR_TB04	384
IRR_VG09	150	IRR_TB05	90
IRR_VG10	147	IRR_TB06	120
IRR_VG12	235	IRR_TB07	680
IRR_VG13	4766	IRR_TB08	1616
IRR_VG11	380	IRR_TB09	1090
IRR_VG14	835	IRR_TB10	100
IRR_TB11	2311	IRR_TB01	80
IRR_TB12	1305	IRR_TB02	6260
IRR_TB13	666	IRR_TK01	1075
IRR_TB14	380	IRR_TK02	280
IRR_TB15	735	IRR_TK03	436
IRR_TB17	1910	IRR_TK04	14,500
IRR_TB18	155	IRR_TK05	295
IRR_TB19	1407	–	

downscaling to match the spatial scale of the area of interest further adds uncertainty to the assessment (Dessai and Hulme, 2004; Shaw et al., 2009; Sheppard et al., 2011; Stéphane Hallegatte et al., 2012; Wilby and Dessai, 2010). For this reason, a different approach is used in this study to overcome to limitations of previous assessments.

4. Methodology

The methodology of the research is based largely on the decision scaling framework (Brown et al., 2011; Brown, 2011; Brown et al., 2012; Grijsen, 2014). The overall work flow of the research is shown in Fig. 2.

In the first step, the study explores the vulnerability of the water system in VGTB River Basin. Through consultations with local stakeholders and experts, the key vulnerability area of water shortage is identified. Stakeholders and experts interviewed in the study includes national and local governmental organizations that are responsible for water resources management, agriculture management, disaster management in the research area, and fellow researchers that have experience in studying the hydrological system of the VGTB River Basin. The list of stakeholders and experts, and their relevance to the study is shown in Table 1.

Reliability is chosen as the measurement of system performance, i.e. indicator of water shortage. Reliability in this context is defined as the percentage of time that the water system could meet its demand. For instance, a 70% reliability would indicate that 70% of the time under consideration, the water supply system would be able to provide sufficient water whereas the remaining 30% of the time, water shortage would occur.

The performance threshold, i.e. the minimum required reliability value is also determined within this phase. In the original decision scaling approach, the threshold level is determined based on stakeholder meetings and expert knowledge. However, as the first stakeholder and expert meetings were conducted, it was clear that a one common threshold level was difficult to be obtained. For this reason, an iterative-more than one round of discussion is required.

In the second round of discussion, literature on previous water shortage and drought events were presented and thoroughly analyzed. This is based on the assumption that severe water shortages in the past would provide an indication of the level of hazard and impact that would be deemed unacceptable and require adaptation actions. The information from the literature were then communicated with stakeholders and experts to establish the more extreme events to be further discussed.

In the third round of meeting, the performance threshold was selected among the performance indicators of the system during real water shortage events in the past. More particularly, the performance of the system during water shortage events identified earlier were determined and communicated with the stakeholders and experts. The information on the severity of water shortage events in the past and the corresponding performance indicator were then used to establish the performance threshold for the system.

Additionally, instead of solely relying on the literature and the subjectivity of stakeholders and experts, a cross-check scheme is adopted. Water shortage events reported in the literature and through discussion

Table 3
Domestic water demand nodes.

Node in MIKE BASIN	Township	City/district
WSP_VG01	Kham Duc	Phuoc Son
WSP_VG02	Thanh My	Nam Giang
WSP_VG03	P'rao	Dong Giang
WSP_VG04	Ai Nghia	Dai Loc
WSP_VG05	Da Nang	Da Nang
WSP_TB01	Tra My	Bac Tra My
WSP_TB02	Tien Ky	Tien Phuoc
WSP_TB03	Tan An	Hiep Duc
WSP_TB04	Ha Lam	Thang Binh
WSP_TB04	Dong Phu	Que Son
WSP_TB05	Vinh Dien	Dien Ban
WSP_TB05	Nam Phuoc	Duy Xuyen
WSP_TB05	Hoi An	Hoi An
WSP_TK01	Tam Ky	Tam Ky
WSP_TK01	Phu Thinh	Phu Ninh
WSP_TK02	Nui Thanh	Nui Thanh

Table 4
Industrial water demand nodes.

Node in MIKE BASIN	Industrial area	Location
WSP_TB04	Dong Que Son	Huong An commune, Que Son District, Quang Nam
WSP_TB04	Go Hoang	Binh Lam Commune, Hiep Duc District, Quang Nam
WSP_TK02	Chu Lai	Tam Thien commune, Nui Thanh District, Quang Nam
WSP_TK01	Tam Thang	Tam Thang commune, Tam Ky City, Quang Nam
WSP_TB05	DienNam- Dien Ngoc	Dien Nam-Dien Ngoc commune, Dien Ban District, QN
WSP_TB05	Que Phu	Que Phu commune, Que Son District, Quang Nam
WSP_TB05	Dong Yen	Duy Trinh commune, Duy Xuyen District, Quang Nam
WSP_TK02	Tam Hiep	Tam Ky City, Quang Nam
WSP_TK02	Tam My Tay	My Tay commune, Nui Thanh District, Quang Nam
WSP_TK01	Phu Xuan	Phu Ninh District, Quang Nam
WSP_TK01	Thuan Yen	Tam Ky City, Quang Nam
WSP_TK02	Bac Chu Lai	Tam Hiep commune, Nui Thanh District, Quang Nam
WSP_VG05	Hoa Khanh	Lien Chieu District, Da Nang
	Hoa Khanh extension	Lien Chieu District, Da Nang
	Lieu Chieu	Lien Chieu District, Da Nang
	Hoa Cam	Cam Le District, Da Nang
	Da Nang fishery	Son Tra District, Da Nang
	Da Nang	Son Tra District, Da Nang

with the stakeholders were validated using the Surface Water Supply Index (SWSI). The assumption here is that SWSI could give an indication of the extent of water shortage.

In the second step, a system model was developed using the MIKE BASIN model. There are three main components in the MIKE BASIN model namely the water supply, water demand and water storage components. Water supply comes directly from rainfall in the river basin. Water demand includes agricultural water demand and domestic/industrial water demand (corresponding nodes are listed in Tables 2, 3 and 4). For the purpose of the study, it was assumed that all agricultural crop demand in the river basin was from paddy rice. Domestic and industrial water demand was calculated based on population and the size of the operating industrial areas respectively. Communities living in the rural area relied on wells, and local, small water supply scheme other than water mains supplying scheme. Hence, only domestic water demand for urban area was accounted for as domestic water users. The water storage component is simulated through the use of reservoirs in the river basin. Parametrically varied temperature and precipitation were then used to drive the simulation of the model to determine the reliability of the system. A baseline period of 1986–2005 similar to IPCC's Fifth Assessment Report was used. The use of only temperature and precipitation is due to the significance of these two climate variables in climate change modelling (Maraun et al., 2010).

A total of 21 storage reservoirs, 43 agricultural demand nodes, and 12 domestic/industrial demand nodes were established in the model (Fig. 3).

The third step utilizes information from GCMs. For the study, output from 25 GCMs were used to establish a possible future climate space. The selection of models in this research was mainly due to the easy accessibility and the ability to store a large amount of data on limited storage capacity. In addition, the selected 25 GCMs have been widely used in applications in Viet Nam as well as being thoroughly tested for their performances and skills (Hidalgo and Alfaro, 2015; Jury et al., 2015; Lutz et al., 2016; Mehran et al., 2014; Miao et al., 2014; Rupp et al., 2013; Supharatid, 2016).

Three cases of GCMs are further analyzed including the maximum consensus scenario, the best case scenario, and the worst case scenario. A maximum consensus scenario is where the highest number of GCMs predict the same range of change in precipitation and temperature. A best case scenario represents minimum changes in both temperature and precipitation. A worst case scenario represents the highest increase in temperature combined with highest decrease in precipitation. A similar approach using the consensus among multiple GCMs has been used by the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia (Clarke et al., 2011) and adopted both in Viet Nam and Australia.

The last step involves combining the information from the MIKE BASIN simulations with the information from the GCMs. Information

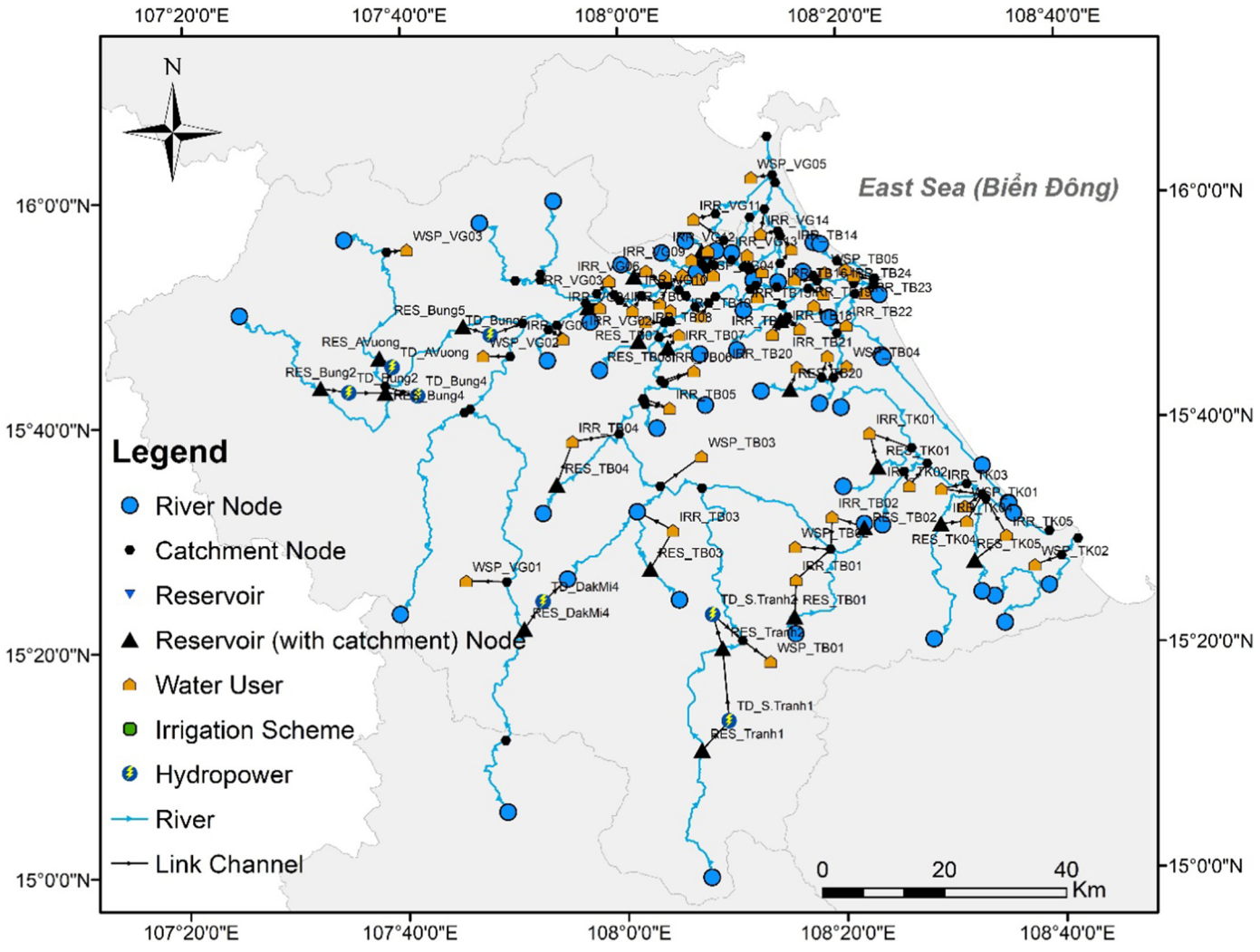

Fig. 3. The MIKE BASIN model for VGTB River Basin.

Table 5
SWSI value in year 1998 for VGTB River Basin.

	Average	Drought classification
January	−3.8	Extremely dry
February	−3.8	Extremely dry
March	−4.0	Extremely dry
April	−3.9	Extremely dry
May	−3.7	Extremely dry
June	−4.2	Extremely dry
July	−3.9	Extremely dry
August	−4.0	Extremely dry
September	0.0	Near average
October	−2.1	Moderately dry
November	3.5	Extremely wet
December	2.9	Moderately wet

on the reliability of the water system from different temperature and precipitation range is combined with the three likely cases of maximum consensus, best-case and worst-case scenario from the GCM analysis.

5. Results and discussions

5.1. Bottom-up information

Through discussions with local stakeholders and experts, it was determined that water shortage with similar severity to the 1998 water shortage event would be unacceptable and require adaptation action. For this reason, reliability of the water system in 1998 is used as a system performance threshold.

Water shortage in 1988 was further validated using SWSI (refer to Table 5). Water shortages occurred basin-wide in 1998 between January through to October with the exception of November and December. In other words, the dry season in the river basin in 1998 experienced significantly less than average water availability while the rainy season experienced somewhat wetter condition. SWSI for January through to August in 1998 were lower than the −3.0 benchmark, classifying these months as extremely dry. SWSI for September and October is classified as near average and moderately dry respectively.

The extremely wet and moderately wet classification for November and December in 1998 could be partly attributed to the El Nino Southern Oscillation (ENSO) active in 1998. As ENSO involves a warm phase (El Nino) and a cold phase (La Nina). During the warm phase of ENSO, El Nino, water shortage occurred due to increased temperature and drier conditions. However, as El Nino phase out and La Nina phase in, the opposite condition occurred where wetter condition is observed. The warm phase of ENSO occurred late 1997 and early 1998, leading to dry conditions in early 1998. However, as El Nino phase out at the end of 1998 and La Nina phase in, the higher than normal water abundance in late 1998 could be explained.

A quick comparison of the SWSI in 1998 and other reported water shortage events is shown in Fig. 4. For the dry season from January through to August, the calculated SWSI value of 1998 is consistently within the first quartile of the distribution of SWSI values. Calculated SWSI in August 1998 bares the minimum value- indicating the most severe water shortage event. Under a monthly scale, SWSI in 1998 does not indicate that any particular month other than August represents the most severe water shortage event. However, under the annual scale, no other SWSI values in other years exhibit a consistently low SWSI for consecutive months similar to 1998. In other words, there is no similar prolonged dry condition in other water shortage events as observed in 1998. This in turn, shows the severity of the water shortage event that occurred during 1998.

Reliability of the water supply system in 1998 is thus used as the performance threshold. A lowest reliability of 92% is observed in the MIKE BASIN simulation in 1998. Previous studies by Brown et al. (2011) and Brown et al. (2012) also established a similar reliability value of 95%. Thus, the 92% reliability threshold value is deemed reasonable and justifiable.

A total of 73 MIKE Basin model runs were performed with varied precipitation and temperature values. Of the 55 water demand nodes in the MIKE BASIN model, only 9 nodes exhibit water shortage conditions under the range of temperature and precipitation analyzed. An example of reliability plotted against changes in temperature and precipitation for node IRR_VG07 is as shown in Fig. 5. In this example, it can be seen that under the range of climate conditions evaluated, the irrigation node faces water shortage challenge, thus, the irrigated area is highly vulnerable to climate change.

The summary of temperature and precipitation change together with irrigation nodes that exhibit reliability lower than the performance threshold is shown in Table 6. For easy readability, the "IRR_" prefixes in the name of the irrigation nodes have been removed. In general for all other irrigation nodes, there is an inverse relationship between reliability and increase in temperature, i.e. the higher the increase in temperature, the lower the reliability. On the

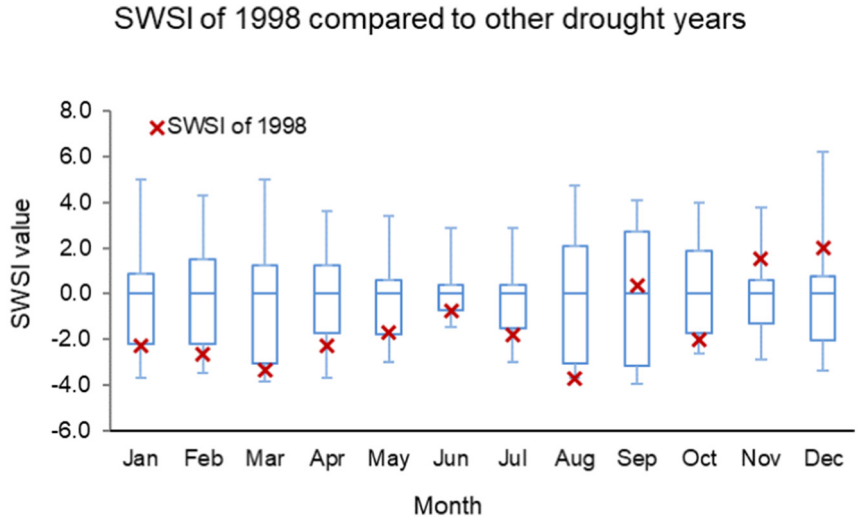

Fig. 4. SWSI of 1998 in comparison with other water shortage events.

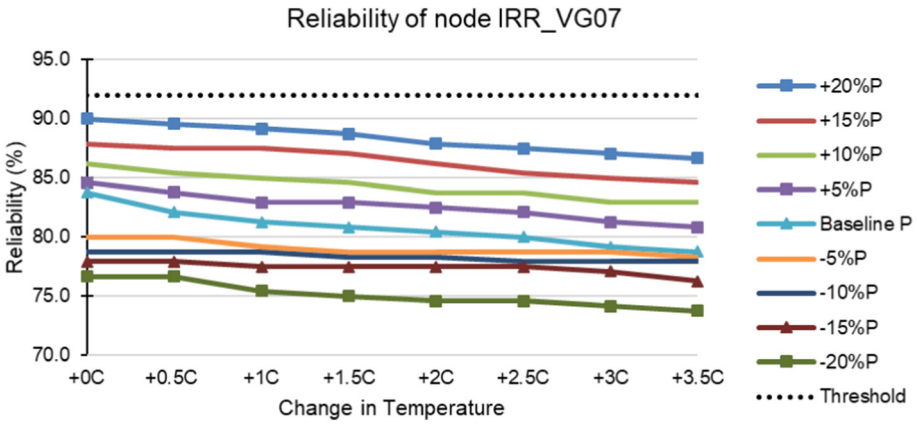

Fig. 5. Reliability of node IRR_VG07.

contrary, the relationship between reliability and decrease in precipitation is of a proportional nature, i.e. the further the decrease in precipitation, the lesser the reliability. Ultimately, a combined increase in temperature and decrease in precipitation would lead to even significantly lower reliability. From the 9 irrigation nodes that faces water shortage, 8777 ha of crop are at risk.

5.2. Top-down information

The GCM model outputs are summarized in Tables 7, 8 and 9. The number in each cell represents the number of model output predictions within the same range of temperature and precipitation change. The higher the number in each individual cell shows a higher level of agreement between GCMs. In addition, the more clustered the higher numbered cells indicates a higher precision of GCM outputs. In other words, GCM outputs converge on a smaller range of temperature and precipitation change. On the other hand, the higher the spread in the range of the high numbered cells indicates the higher spread in predictions of GCMs, hence, implies higher uncertainty.

Overall, analyzing future precipitation and temperature predictions from GCMs showed a higher spread of model agreement in the long run. In the short-term between 2016 and 2035, there exist an absolute highest number of model agreement with 25 model outputs predicting the same range of precipitation and temperature change. This is not the case for later time periods, hence, implicates the difficulties in using climate science to drive adaptation measures and reiterate the uncertainties of previous effort attempting to downscale one or a few GCMs.

5.3. Combining top-down and bottom-up information

Three key cases of maximum consensus, best-case scenario, and worst-case scenario are further evaluated.

Under a maximum consensus scenario, 5 irrigation nodes would be under water shortage conditions throughout the time period

Table 6
Irrigation nodes with reliability below threshold.

	+0 °C	+0.5 °C	+1 °C	+1.5 °C	+2 °C	+2.5 °C	+3 °C	+3.5 °C
+20%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23
+15%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23
+10%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23
+5%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23
Baseline P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG09, VG13, TB15, TB21, TB23
−5%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG09, VG13, TB15, TB21, TB23	VG07, VG09, VG13, TB15, TB21, TB23	VG07, VG09, VG13, TB15, TB21, TB23	VG07, VG09, VG13, TB13, TB15, TB21, TB23	VG07, VG09, VG13, TB13, TB15, TB21, TB23	VG07, VG09, VG13, TB13, TB15, TB21, TB23
−10%P	VG07, VG09, VG13, TB09, TB15, TB21, TB23	VG07, VG09, VG13, TB09, TB15, TB21, TB23	VG07, VG09, VG13, TB09, TB13, TB15, TB21, TB23	VG07, VG09, VG13, TB09, TB13, TB15, TB21, TB23	VG07, VG09, VG13, TB09, TB13, TB15, TB21, TB23	VG07, VG09, VG12, VG13, TB09, TB13, TB15, TB21, TB23	VG07, VG09, VG12, VG13, TB09, TB13, TB15, TB21, TB23	VG07, VG09, VG12, VG13, TB09, TB13, TB15, TB21, TB23
−15%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23
−20%P	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23	VG07, VG13, TB15, TB21, TB23

Table 7
Climate future for time period 2016–2035 (all scenarios).

		Annual Surface temperature (°C)			
		Slightly warmer < +0.5	Warmer +0.5 to +1.5	Hotter +1.5 to +3.0	Much Hotter >+3.0
Annual Rainfall (%)	Much wetter > +15	0	0	0	0
	Wetter +5.0 to +15.0	2	6	1	0
	Little Change -5.0 to +5.0	9	25	0	1
	Drier -15.0 to -5.0	0	10	1	0
	Much Drier <-15.0	0	0	0	0

Table 8
Climate future for time period 2046–2065 (all scenarios).

		Annual Surface temperature (°C)			
		Slightly warmer < +0.5	Warmer +0.5 to +1.5	Hotter +1.5 to +3.0	Much Hotter >+3.0
Annual Rainfall (%)	Much wetter > +15	0	1	1	1
	Wetter +5.0 to +15.0	0	9	6	0
	Little Change -5.0 to +5.0	1	11	9	1
	Drier -15.0 to -5.0	0	7	6	1
	Much Drier <-15.0	0	1	0	0

Table 9
Climate future for time period 2080–2099 (all scenarios).

		Annual Surface temperature (°C)			
		Slightly warmer < +0.5	Warmer +0.5 to +1.5	Hotter +1.5 to +3.0	Much Hotter >+3.0
Annual Rainfall (%)	Much wetter > +15	0	0	6	2
	Wetter +5.0 to +15.0	0	11	6	4
	Little Change -5.0 to +5.0	1	6	8	6
	Drier -15.0 to -5.0	0	0	4	1
	Much Drier <-15.0	0	0	0	0

analyzed. A total of 6636 ha of crops would be vulnerable to water shortages (Table 10). Furthermore, under the maximum consensus scenario, the amount of water demand deficit varies between the periods. For the first two period of 2016–2035 and 2045–2066, total water demand deficit is between 13.7 million m^3 and 16.9 million m^3. Given that GCMs predict a wetter future by the end of the century, only between 11.8 and 15.6 million m^3 of water is short in the last time period.

Under a best-case scenario, for 3 time periods 2016–2035, 2045–2066, and 2085–2099, 6636 ha of crop from 5 irrigation nodes would face water shortages (Table 11). The effect of this case is similar to the maximum consensus case. In particular, the same 5 irrigation area determined to be facing water challenges in the maximum consensus case would also be vulnerable. Under a best-case scenario, water deficit for all three periods are similar. It would require between 13.3 and 15.9 million m^3 of water to meet the water deficit for agricultural purposes.

Under a worst-case scenario 9 irrigation nodes would face water shortage problems. Consequently, 8777 ha of crop under risks will face water shortages (refer to Table 12). Water deficit under the worst-case scenario is also higher than water deficit determined in the other two scenarios. For the first period of 2016–2035, an addition of between 15.5 and 20.4 million m^3 would be required to meet irrigation demand. For the second period between 2045 and 2066, an addition of 14.7 to 20.2 million m^3 of water is needed. For the last period, between 15.5 and 20.9 million m^3 is needed.

An interesting aspect of the deficit is that water shortages only occurred within the summer- fall crop calendar, especially between the months of April and July. The main reason is due to the crop cycle calendar and the higher irrigation water demand during drier months where less precipitation is received.

6. Conclusions

The study has adopted a combined top-down and bottom-up climate change impact assessment for the VGTB River Basin. Bottom-up information was provided using a classic climate sensitivity test. Temperature and precipitation were parametrically varied to enable the determination of problematic conditions. Additionally, top-down information from 25 GCMs were used to obtain possible future climate conditions.

The study has been successful in identifying key vulnerable climate conditions of the VGTB River Basin in the context of water shortage. This includes the maximum-consensus, best-case, and worst-case scenario of GCMs. Between 6636 and 8777 ha in the river basin faces water shortage challenge in the future. The information provided are more meaningful and thus would be beneficial for climate change adaptation policies and measures.

There also exist a number of limitations to the study. This includes the various assumptions used and land use change unaccounted for. The exclusion of other types of crops in the river basin could affect the overall water demand in the MIKE BASIN model, hence the accuracy of the study.

Finally, the results could be expected to be able to provide a framework for climate adaptation in other river systems in Viet Nam. Although there are certain differences between other river systems in Viet Nam such as rainy and dry season initiation period, the majority of river basins in Viet Nam faces the same challenges if not even more severe than the VGTB River Basin. For this reason, being able to successfully provide a combined top-down and bottom up impact assessment for the VGTB River Basin would be beneficial for the adoption of the approach in other river basins.

Table 10
Maximum consensus scenario of GCM outputs.

	2016–2035	2045–2066	2085–2099
Case	Warmer, little change	Warmer, little change	Warmer, wetter
Nodes affected	IRR_VG07, IRR_VG13, IRR_TB15, IRR_TB21, and IRR_TB23	IRR_VG07, IRR_VG13, IRR_TB15, IRR_TB21, and IRR_TB23	IRR_VG07, IRR_VG13, IRR_TB15, IRR_TB21, and IRR_TB23
Area affected	6636 ha	6636 ha	6636 ha
Water deficit	13.7–16.9 million m^3	13.7–16.9 million m^3	11.8–15.6 million m^3

Table 11
Best-case scenario of GCM outputs.

	2016–2035	2045–2066	2085–2099
Case	Slightly warmer, little change	Slightly warmer, little change	Slightly warmer, little change
Nodes	IRR_VG07, IRR_VG13, IRR_TB15, IRR_TB21, and IRR_TB23	IRR_VG07, IRR_VG13, IRR_TB15, IRR_TB21, and IRR_TB23	IRR_VG07, IRR_VG13, IRR_TB15, IRR_TB21, and IRR_TB23
Area affected	6636 ha	6636 ha	6636 ha
Water deficit	13.3–15.9 million m^3	13.3–15.9 million m^3	13.3–15.9 million m^3

Table 12
Worst-case scenario of GCM outputs.

	2016–2035	2045–2066	2085–2099
Case	Hotter, drier	Warmer, much drier	Much hotter, drier
Nodes	IRR_VG07, IRR_VG09, IRR_VG12, IRR_VG13, IRR_VG09, IRR_TB13, IRR_TB15, IRR_TB21, IRR_TB23	IRR_VG07, IRR_VG09, IRR_VG12, IRR_VG13, IRR_VG09, IRR_TB13, IRR_TB15, IRR_TB21, IRR_TB23	IRR_VG07, IRR_VG09, IRR_VG12, IRR_VG13, IRR_VG09, IRR_TB13, IRR_TB15, IRR_TB21, IRR_TB23
Area affected	8777 ha	8777 ha	8777 ha
Water deficit	15.5–20.4 million m^3	14.7–20.2 million m^3	15.5–20.9 million m^3

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Author contributions

Tran Van Tra led the research design, data processing, analysis, and drafted the article. Prof. Dr. Nguyen Xuan Thinh and Prof. Dr. Stefan Greiving supervised the research. All authors have read and approved the final version of this manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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